

# Chapter 6- A Tour of the Cell

## Overview: The Importance of Cells

- **All organisms are made of cells.**
  - Many organisms are single-celled.
  - Even in multicellular organisms, the cell is the basic unit of structure and function.
- The cell is the simplest collection of matter that can live.
- All cells are related by their descent from earlier cells.

## A. How We Study Cells

### Objectives:

1. Distinguish between magnification and resolving power.
1. Describe the principles, advantages, and limitations of the light microscope, transmission electron microscope, and scanning electron microscope.
3. Describe the major steps of cell fractionation and explain why it is a useful technique.

### *1. Microscopes provide windows to the world of the cell.*

- The discovery and early study of cells progressed with the invention of microscopes in 1590 and their improvement in the 17th century.
- In a light microscope (LM), visible light passes through the specimen and then through glass lenses.
  - The lenses refract light such that the image is magnified into the eye or onto a video screen.
- Microscopes vary in magnification and resolving power.
  - **Magnification** is the ratio of an object's image to its real size.
  - **Resolving power** is a measure of image clarity.
    - It is the minimum distance two points can be separated and still be distinguished as two separate points.
    - Resolution is limited by the shortest wavelength of the radiation used for imaging.
- The minimum resolution of a light microscope is about 200 nanometers (nm), the size of a small bacterium.
- Light microscopes can magnify effectively to about 1,000 times the size of the actual specimen.
  - At higher magnifications, the image blurs.
- Techniques developed in the 20th century have enhanced contrast and enabled particular cell components to be stained or labeled so they stand out.
- While a light microscope can resolve individual cells, it cannot resolve much of the internal anatomy, especially the **organelles**.
- To resolve smaller structures, we use an **electron microscope (EM)**, which focuses a beam of electrons through the specimen or onto its surface.
  - Because resolution is inversely related to wavelength used, electron microscopes (whose electron beams have shorter wavelengths than visible light) have finer resolution.
  - Theoretically, the resolution of a modern EM could reach 0.002 nanometer (nm), but the practical limit is closer to about 2 nm.
- **Transmission electron microscopes (TEMs)** are used mainly to study the internal ultrastructure of cells.

- A TEM aims an electron beam through a thin section of the specimen.
  - The image is focused and magnified by electromagnets.
  - To enhance contrast, the thin sections are stained with atoms of heavy metals.
  - **Scanning electron microscopes (SEMs)** are useful for studying surface structures.
    - The sample surface is covered with a thin film of gold.
    - The beam excites electrons on the surface of the sample.
    - These secondary electrons are collected and focused on a screen.
    - The result is an image of the topography of the specimen.
    - The SEM has great depth of field, resulting in an image that seems three-dimensional.
  - Electron microscopes reveal organelles that are impossible to resolve with the light microscope.
    - However, electron microscopes can only be used on dead cells.
  - Light microscopes do not have as high a resolution, but they can be used to study live cells.
  - Microscopes are major tools in **cytology**, the study of cell structures.
  - Cytology combined with biochemistry, the study of molecules and chemical processes in metabolism, to produce modern cell biology.
- 2. Cell biologists can isolate organelles to study their functions.**
- The goal of **cell fractionation** is to separate the major organelles of the cells so their individual functions can be studied.
  - This process is driven by an **ultracentrifuge**, a machine that can spin at up to 130,000 revolutions per minute and apply forces of more than 1 million times gravity (1,000,000 g).
  - Fractionation begins with homogenization, gently disrupting the cell.
  - The homogenate is spun in a centrifuge to separate heavier pieces into the pellet while lighter particles remain in the supernatant.
    - As the process is repeated at higher speeds and for longer durations, smaller and smaller organelles can be collected in subsequent pellets.
  - Cell fractionation prepares isolates of specific cell components.
  - This enables the functions of these organelles to be determined, especially by the reactions or processes catalyzed by their proteins.
    - For example, one cellular fraction was enriched in enzymes that function in cellular respiration.
    - Electron microscopy revealed that this fraction is rich in mitochondria.
    - This evidence helped cell biologists determine that mitochondria are the site of cellular respiration.
  - Cytology and biochemistry complement each other in correlating cellular structure and function.

## **B. A Panoramic View of the Cell**

**Objectives:**

1. Distinguish between prokaryotic and eukaryotic cells.
1. Explain why there are both upper and lower limits to cell size.
2. Explain the advantages of compartmentalization in eukaryotic cells.

**Misconception:**

Most students can assemble an accurate list of the differences between prokaryotic and eukaryotic cells. Despite this, many students have fundamental misconceptions about prokaryotic cells.

- Comparisons of size for prokaryotic and eukaryotic cells usually give values for typical diameter or length of cells. Students who are unfamiliar with the relationship between length and volume will not appreciate the tremendous difference in volume between prokaryotic and eukaryotic cells.
- Many students think that prokaryotic cells lack internal organization because they lack membrane-bound organelles. Clarify to students that prokaryotes are relatively simple but have considerable internal organization. Point out that the plasma membrane of prokaryotic cells plays important roles similar to those of the membranes of eukaryotic organelles.
- Students often fail to appreciate the metabolic capabilities of prokaryotic cells. Virtually all known metabolic pathways arose in prokaryotes. Prokaryotes live in almost all known environments, and display a great variety of complex biochemical adaptations to these environments. Prokaryotes are far more biochemically diverse than eukaryotes.

***1. Prokaryotic and eukaryotic cells differ in size and complexity.***

- All cells are surrounded by a **plasma membrane**.
- The semifluid substance within the membrane is the **cytosol**, containing the organelles.
- All cells contain **chromosomes** that have genes in the form of DNA.
- All cells also have **ribosomes**, tiny organelles that make proteins using the instructions contained in genes.
- A major difference between prokaryotic and eukaryotic cells is the location of chromosomes.
- In a eukaryotic cell, chromosomes are contained in a membrane-enclosed organelle, the **nucleus**.
- In a **prokaryotic cell**, the DNA is concentrated in the **nucleoid** without a membrane separating it from the rest of the cell.
- In **eukaryote cells**, the chromosomes are contained within a membranous nuclear envelope.
- The region between the nucleus and the plasma membrane is the **cytoplasm**.
  - °All the material within the plasma membrane of a prokaryotic cell is cytoplasm.
- Within the cytoplasm of a eukaryotic cell are a variety of membrane-bound organelles of specialized form and function.
  - °These membrane-bound organelles are absent in prokaryotes.
- Eukaryotic cells are generally much bigger than prokaryotic cells.
- The logistics of carrying out metabolism set limits on cell size.
  - °At the lower limit, the smallest bacteria, mycoplasmas, are between 0.1 to 1.0 micron.
  - °Most bacteria are 1–10 microns in diameter.
  - °Eukaryotic cells are typically 10–100 microns in diameter.

- Metabolic requirements also set an upper limit to the size of a single cell.
- As a cell increases in size, its volume increases faster than its surface area.  
°Smaller objects have a greater ratio of surface area to volume.
- The **plasma membrane** functions as a selective barrier that allows the passage of oxygen, nutrients, and wastes for the whole volume of the cell.
- The volume of cytoplasm determines the need for this exchange.
- Rates of chemical exchange across the plasma membrane may be inadequate to maintain a cell with a very large cytoplasm.
- The need for a surface sufficiently large to accommodate the volume explains the microscopic size of most cells.
- Larger organisms do not generally have *larger* cells than smaller organisms—simply *more* cells.
- Cells that exchange a lot of material with their surroundings, such as intestinal cells, may have long, thin projections from the cell surface called microvilli. Microvilli increase surface area without significantly increasing cell volume.

## ***2. Internal membranes compartmentalize the functions of a eukaryotic cell.***

- A eukaryotic cell has extensive and elaborate internal membranes, which partition the cell into compartments.
- These membranes also participate directly in metabolism, as many enzymes are built into membranes.
- The compartments created by membranes provide different local environments that facilitate specific metabolic functions, allowing several incompatible processes to go on simultaneously in a cell.
- The general structure of a biological membrane is a double layer of phospholipids.
- Other lipids and diverse proteins are embedded in the lipid bilayer or attached to its surface.
- Each type of membrane has a unique combination of lipids and proteins for its specific functions.  
°For example, enzymes embedded in the membranes of mitochondria function in cellular respiration.

## **C. The Nucleus and Ribosomes**

## Objectives:

1. Describe the structure and function of the nuclear envelope, including the role of the pore complex.
2. Briefly explain how the nucleus controls protein synthesis in the cytoplasm.
3. Explain how the nucleolus contributes to protein synthesis.
4. Describe the structure and function of a eukaryotic ribosome.
5. Distinguish between free and bound ribosomes in terms of location and function.

### *1. The nucleus contains a eukaryotic cell's genetic library.*

- The **nucleus** contains most of the genes in a eukaryotic cell.
  - Additional genes are located in mitochondria and chloroplasts.
- The nucleus averages about 5 microns in diameter.
- The nucleus is separated from the cytoplasm by a double membrane called the **nuclear envelope**.
  - The two membranes of the nuclear envelope are separated by 20–40 nm.
  - The envelope is perforated by pores that are about 100 nm in diameter.
  - At the lip of each pore, the inner and outer membranes of the nuclear envelope are fused to form a continuous membrane.
  - A protein structure called a **pore complex** lines each pore, regulating the passage of certain large macromolecules and particles.
- The nuclear side of the envelope is lined by the **nuclear lamina**, a network of protein filaments that maintains the shape of the nucleus.
- There is evidence that a framework of fibers called the **nuclear matrix** extends through the nuclear interior.
- Within the nucleus, the DNA and associated proteins are organized into discrete units called **chromosomes**, structures that carry the genetic information.
- Each chromosome is made up of fibrous material called **chromatin**, a complex of proteins and DNA.
  - Stained chromatin appears through light microscopes and electron microscopes as a diffuse mass.
- As the cell prepares to divide, the chromatin fibers coil up and condense, becoming thick enough to be recognized as the familiar chromosomes.
- Each eukaryotic species has a characteristic number of chromosomes.
  - A typical human cell has 46 chromosomes.
  - A human sex cell (egg or sperm) has only 23 chromosomes.
- In the nucleus is a region of densely stained fibers and granules adjoining chromatin, the **nucleolus**.
  - In the nucleolus, ribosomal RNA (rRNA) is synthesized and assembled with proteins from the cytoplasm to form ribosomal subunits.
  - The subunits pass through the nuclear pores to the cytoplasm, where they combine to form ribosomes.
- The nucleus directs protein synthesis by synthesizing messenger RNA (mRNA).
  - The mRNA travels to the cytoplasm through the nuclear pores and combines with ribosomes to translate its genetic message into the primary structure of a specific polypeptide.

### *2. Ribosomes build a cell's proteins.*

- **Ribosomes**, containing rRNA and protein, are the organelles that carry out protein synthesis.
  - Cell types that synthesize large quantities of proteins (e.g., pancreas cells) have large numbers of ribosomes and prominent nucleoli.

- Some ribosomes, *free ribosomes*, are suspended in the cytosol and synthesize proteins that function within the cytosol.
- Other ribosomes, *bound ribosomes*, are attached to the outside of the endoplasmic reticulum or nuclear envelope.
  - °These synthesize proteins that are either included in membranes or exported from the cell.
- Ribosomes can shift between roles depending on the polypeptides they are synthesizing.

## D. The Endomembrane System

### Objectives:

1. List the components of the endomembrane system, and describe the structure and functions of each component
2. Compare the structure and functions of smooth and rough ER.
3. Explain the significance of the cis and trans sides of the Golgi apparatus.
4. Describe the cisternal maturation model of Golgi function.
5. Describe three examples of intracellular digestion by lysosomes.
6. Name three different kinds of vacuoles, giving the function of each kind.

### Overview:

- Many of the internal membranes in a eukaryotic cell are part of the **endomembrane system**.
- These membranes are either directly continuous or connected via transfer of **vesicles**, sacs of membrane.
  - In spite of these connections, these membranes are diverse in function and structure.
  - The thickness, molecular composition and types of chemical reactions carried out by proteins in a given membrane may be modified several times during a membrane's life.
- The endomembrane system includes the nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and the plasma membrane.

### *1. The endoplasmic reticulum manufactures membranes and performs many other biosynthetic functions.*

- The **endoplasmic reticulum (ER)** accounts for half the membranes in a eukaryotic cell.
- The ER includes membranous tubules and internal, fluid-filled spaces called cisternae.
- The ER membrane is continuous with the nuclear envelope, and the cisternal space of the ER is continuous with the space between the two membranes of the nuclear envelope.
- There are two connected regions of ER that differ in structure and function.
  - **Smooth ER** looks smooth because it lacks ribosomes.
  - **Rough ER** looks rough because ribosomes (bound ribosomes) are attached to the outside, including the outside of the nuclear envelope.
- The smooth ER is rich in enzymes and plays a role in a variety of metabolic processes.
  - Enzymes of smooth ER synthesize lipids, including oils, phospholipids, and steroids.
  - These include the sex hormones of vertebrates and adrenal steroids.
  - In the smooth ER of the liver, enzymes help detoxify poisons and drugs such as alcohol and barbiturates.
    - Frequent use of these drugs leads to the proliferation of smooth ER in liver cells, increasing the rate of detoxification.
    - This increases tolerance to the target and other drugs, so higher doses are required to achieve the same effect.
  - Smooth ER stores calcium ions.
    - Muscle cells have a specialized smooth ER that pumps calcium ions from the cytosol and stores them in its cisternal space.
    - When a nerve impulse stimulates a muscle cell, calcium ions rush from the ER into the cytosol, triggering contraction.
    - Enzymes then pump the calcium back, readying the cell for the next stimulation.
- Rough ER is especially abundant in cells that secrete proteins.
  - As a polypeptide is synthesized on a ribosome attached to rough ER, it is threaded into the cisternal space through a pore formed by a protein complex in the ER membrane.
  - As it enters the cisternal space, the new protein folds into its native conformation.

◦Most secretory polypeptides are **glycoproteins**, proteins to which a carbohydrate is attached.

◦Secretory proteins are packaged in **transport vesicles** that carry them to their next stage.

- Rough ER is also a membrane factory.

◦Membrane-bound proteins are synthesized directly into the membrane.

◦Enzymes in the rough ER also synthesize phospholipids from precursors in the cytosol.

◦As the ER membrane expands, membrane can be transferred as transport vesicles to other components of the endomembrane system.

## **2. The Golgi apparatus is the shipping and receiving center for cell products.**

- Many transport vesicles from the ER travel to the **Golgi apparatus** for modification of their contents.

- The Golgi is a center of manufacturing, warehousing, sorting, and shipping.

- The Golgi apparatus is especially extensive in cells specialized for secretion.

- The Golgi apparatus consists of flattened membranous sacs—cisternae—looking like a stack of pita bread.

◦The membrane of each cisterna separates its internal space from the cytosol.

◦One side of the Golgi, the *cis* side, is located near the ER. The *cis* face receives material by fusing with transport vesicles from the ER.

◦The other side, the *trans* side, buds off vesicles that travel to other sites.

- During their transit from the *cis* to the *trans* side, products from the ER are usually modified.

- The Golgi can also manufacture its own macromolecules, including pectin and other noncellulose polysaccharides.

- The Golgi apparatus is a very dynamic structure.

◦According to the *cisternal maturation model*, the cisternae of the Golgi progress from the *cis* to the *trans* face, carrying and modifying their protein cargo as they move.

- Finally, the Golgi sorts and packages materials into transport vesicles.

◦Molecular identification tags are added to products to aid in sorting.

◦Products are tagged with identifiers such as phosphate groups. These act like ZIP codes on mailing labels to identify the product's final destination.

## **3. Lysosomes are digestive compartments.**

- A **lysosome** is a membrane-bound sac of hydrolytic enzymes that an animal cell uses to digest macromolecules.

- Lysosomal enzymes can hydrolyze proteins, fats, polysaccharides, and nucleic acids.

- These enzymes work best at pH 5.

◦Protons in the lysosomal membrane pump hydrogen ions from the cytosol into the lumen of the lysosomes.

◦Rupture of one or a few lysosomes has little impact on a cell because the lysosomal enzymes are not very active at the neutral pH of the cytosol.

◦However, massive rupture of many lysosomes can destroy a cell by autodigestion.

- Lysosomal enzymes and membrane are synthesized by rough ER and then transferred to the Golgi apparatus for further modification.

- Proteins on the inner surface of the lysosomal membrane are spared by digestion by their three-dimensional conformations, which protect vulnerable bonds from hydrolysis.

- Lysosomes carry out intracellular digestion in a variety of circumstances.

- *Amoebas* eat by engulfing smaller organisms by **phagocytosis**.

◦The food vacuole formed by phagocytosis fuses with a lysosome, whose enzymes digest the food.



- As the polymers are digested, monomers pass to the cytosol to become nutrients for the cell.
- Lysosomes can play a role in recycling of the cell's organelles and macromolecules.
  - This recycling, or *autophagy*, renews the cell.
  - During autophagy, a damaged organelle or region of cytosol becomes surrounded by membrane.
  - A lysosome fuses with the resulting vesicle, digesting the macromolecules and returning the organic monomers to the cytosol for reuse.
- The lysosomes play a critical role in the programmed destruction of cells in multicellular organisms.
  - This process plays an important role in development.
  - The hands of human embryos are webbed until lysosomes digest the cells in the tissue between the fingers.
  - This important process is called *programmed cell death*, or **apoptosis**.

#### **4. Vacuoles have diverse functions in cell maintenance.**

- Vesicles and vacuoles (larger versions) are membrane-bound sacs with varied functions.
  - Food vacuoles** are formed by phagocytosis and fuse with lysosomes.
  - Contractile vacuoles**, found in freshwater protists, pump excess water out of the cell to maintain the appropriate concentration of salts.
  - A large **central vacuole** is found in many mature plant cells.
    - The membrane surrounding the central vacuole, the **tonoplast**, is selective in its transport of solutes into the central vacuole.
    - The functions of the central vacuole include stockpiling proteins or inorganic ions, disposing of metabolic byproducts, holding pigments, and storing defensive compounds that defend the plant against herbivores.
    - Because of the large vacuole, the cytosol occupies only a thin layer between the plasma membrane and the tonoplast. The presence of a large vacuole increases surface area to volume ratio for the cell.

## **E. Other Membranous Organelles**

### **Objectives:**

1. Briefly describe the energy conversions carried out by mitochondria and chloroplasts.
2. Describe the structure of a mitochondrion and explain the importance of compartmentalization in mitochondrial function.
3. Distinguish among amyloplasts, chromoplasts, and chloroplasts.
4. Identify the three functional compartments of a chloroplast. Explain the importance of compartmentalization in chloroplast function.
5. Describe the evidence that mitochondria and chloroplasts are semiautonomous organelles.
6. Explain the roles of peroxisomes in eukaryotic cells.

***1. Mitochondria and chloroplasts are the main energy transformers of cells.***

- Mitochondria and chloroplasts are the organelles that convert energy to forms that cells can use for work.
- **Mitochondria** are the sites of cellular respiration, generating ATP from the catabolism of sugars, fats, and other fuels in the presence of oxygen.
- **Chloroplasts**, found in plants and algae, are the sites of photosynthesis.
  - °They convert solar energy to chemical energy and synthesize new organic compounds such as sugars from CO<sub>2</sub> and H<sub>2</sub>O.
- Mitochondria and chloroplasts are not part of the endomembrane system.
  - °In contrast to organelles of the endomembrane system, each mitochondrion or chloroplast has two membranes separating the innermost space from the cytosol.
  - °Their membrane proteins are not made by the ER, but rather by free ribosomes in the cytosol and by ribosomes within the organelles themselves.
- Both organelles have small quantities of DNA that direct the synthesis of the polypeptides produced by these internal ribosomes.
- Mitochondria and chloroplasts grow and reproduce as semiautonomous organelles.
- Almost all eukaryotic cells have mitochondria.
  - °There may be one very large mitochondrion or hundreds to thousands of individual mitochondria.
  - °The number of mitochondria is correlated with aerobic metabolic activity.
  - °A typical mitochondrion is 1–10 microns long.
  - °Mitochondria are quite dynamic: moving, changing shape, and dividing.
- Mitochondria have a smooth outer membrane and a convoluted inner membrane with infoldings called **cristae**.
  - °The inner membrane divides the mitochondrion into two internal compartments.
  - °The first is the intermembrane space, a narrow region between the inner and outer membranes.
  - °The inner membrane encloses the **mitochondrial matrix**, a fluid-filled space with DNA, ribosomes, and enzymes.
  - °Some of the metabolic steps of cellular respiration are catalyzed by enzymes in the matrix.
  - °The cristae present a large surface area for the enzymes that synthesize ATP.
- The chloroplast is one of several members of a generalized class of plant structures called **plastids**.
  - °Amyloplasts are colorless plastids that store starch in roots and tubers.
  - °Chromoplasts store pigments for fruits and flowers.
  - °Chloroplasts contain the green pigment chlorophyll as well as enzymes and other molecules that function in the photosynthetic production of sugar.

- Chloroplasts measure about 2 microns  $\times$  5 microns and are found in leaves and other green organs of plants and algae.
- The contents of the chloroplast are separated from the cytosol by an envelope consisting of two membranes separated by a narrow intermembrane space.
- Inside the innermost membrane is a fluid-filled space, the **stroma**, in which float membranous sacs, the **thylakoids**.
  - °The stroma contains DNA, ribosomes, and enzymes.
  - °The thylakoids are flattened sacs that play a critical role in converting light to chemical energy. In some regions, thylakoids are stacked like poker chips into **grana**.
  - °The membranes of the chloroplast divide the chloroplast into three compartments: the intermembrane space, the stroma, and the thylakoid space.
- Like mitochondria, chloroplasts are dynamic structures.
  - °Their shape is plastic, and they can reproduce themselves by pinching in two.
- Mitochondria and chloroplasts are mobile and move around the cell along tracks of the cytoskeleton.

## ***2. Peroxisomes generate and degrade $H_2O_2$ in performing various metabolic functions.***

- Peroxisomes contain enzymes that transfer hydrogen from various substrates to oxygen.
  - °An intermediate product of this process is hydrogen peroxide ( $H_2O_2$ ), a poison.
  - °The peroxisome contains an enzyme that converts  $H_2O_2$  to water.
  - °Some peroxisomes break fatty acids down to smaller molecules that are transported to mitochondria as fuel for cellular respiration.
  - °Peroxisomes in the liver detoxify alcohol and other harmful compounds.
  - °Specialized peroxisomes, glyoxysomes, convert the fatty acids in seeds to sugars, which the seedling can use as a source of energy and carbon until it is capable of photosynthesis.
- Peroxisomes are bound by a single membrane.
- They form not from the endomembrane system, but by incorporation of proteins and lipids from the cytosol.
- They split in two when they reach a certain size.

## **F. The Cytoskeleton**

### **Objectives:**

1. Describe the functions of the cytoskeleton.
2. Compare the structure, monomers, and functions of microtubules, microfilaments, and intermediate filaments.
3. Explain how the ultrastructure of cilia and flagella relates to their functions.

#### Overview:

- The **cytoskeleton** is a network of fibers extending throughout the cytoplasm.
- The cytoskeleton organizes the structures and activities of the cell.

#### Misconception:

1. It is important to emphasize that cells are not the static, rigid structures familiar to students from schematic drawings and electron micrographs. The term cytoskeleton is taken by some students to imply permanent scaffolding within the cell. Emphasize the continuous assembly and disassembly of cytoskeletal components and the role of the cytoskeleton in movements of organelles. Discuss the flow of membranes and other materials between organelles when teaching about the endomembrane system. Remind students that mitochondria and chloroplasts vary in shape between cells and move and change shape within cells. The message about the dynamic nature of a living cell is best taught by use of time-lapse movies.

#### *1. The cytoskeleton provides support, motility, and regulation.*

- The **cytoskeleton** provides mechanical support and maintains cell shape.
- The cytoskeleton provides anchorage for many organelles and cytosolic enzymes.
- The cytoskeleton is dynamic and can be dismantled in one part and reassembled in another to change the shape of the cell.
- The cytoskeleton also plays a major role in cell motility, including changes in cell location and limited movements of parts of the cell.
- The cytoskeleton interacts with motor proteins to produce motility.
  - °Cytoskeleton elements and motor proteins work together with plasma membrane molecules to move the whole cell along fibers outside the cell.
  - °Motor proteins bring about movements of cilia and flagella by gripping cytoskeletal components such as microtubules and moving them past each other.
  - °The same mechanism causes muscle cells to contract.
- Inside the cell, vesicles can travel along “monorails” provided by the cytoskeleton.
- The cytoskeleton manipulates the plasma membrane to form food vacuoles during phagocytosis.
- Cytoplasmic streaming in plant cells is caused by the cytoskeleton.
- Recently, evidence suggests that the cytoskeleton may play a role in the regulation of biochemical activities in the cell.
- There are three main types of fibers making up the cytoskeleton: **microtubules**, **microfilaments**, and **intermediate filaments**.
- **Microtubules**, the thickest fibers, are hollow rods about 25 microns in diameter and 200 nm to 25 microns in length.
  - °Microtubule fibers are constructed of the globular protein tubulin.
  - °Each tubulin molecule is a dimer consisting of two subunits.
  - °A microtubule changes in length by adding or removing tubulin dimers.

- Microtubules shape and support the cell and serve as tracks to guide motor proteins carrying organelles to their destination.
- Microtubules are also responsible for the separation of chromosomes during cell division.
- In many cells, microtubules grow out from a **centrosome** near the nucleus.
  - These microtubules resist compression to the cell.
- In animal cells, the centrosome has a pair of **centrioles**, each with nine triplets of microtubules arranged in a ring.
  - Before a cell divides, the centrioles replicate.
- A specialized arrangement of microtubules is responsible for the beating of **cilia** and **flagella**.
  - Many unicellular eukaryotic organisms are propelled through water by cilia and flagella.
  - Cilia or flagella can extend from cells within a tissue layer, beating to move fluid over the surface of the tissue.
    - For example, cilia lining the windpipe sweep mucus carrying trapped debris out of the lungs.
- Cilia usually occur in large numbers on the cell surface.
  - They are about 0.25 microns in diameter and 2–20 microns long.
- There are usually just one or a few flagella per cell.
  - Flagella are the same width as cilia, but 10–200 microns long.
- Cilia and flagella differ in their beating patterns.
  - A flagellum has an undulatory movement that generates force in the same direction as the flagellum's axis.
  - Cilia move more like oars with alternating power and recovery strokes that generate force perpendicular to the cilium's axis.
- In spite of their differences, both cilia and flagella have the same ultrastructure.
  - Both have a core of microtubules sheathed by the plasma membrane.
  - Nine doublets of microtubules are arranged in a ring around a pair at the center. This “9 + 2” pattern is found in nearly all eukaryotic cilia and flagella.
  - Flexible “wheels” of proteins connect outer doublets to each other and to the two central microtubules.
  - The outer doublets are also connected by motor proteins.
  - The cilium or flagellum is anchored in the cell by a **basal body**, whose structure is identical to a centriole.
- The bending of cilia and flagella is driven by the arms of a motor protein, **dynein**.
  - Addition and removal of a phosphate group causes conformation changes in dynein.
  - Dynein arms alternately grab, move, and release the outer microtubules.
  - Protein cross-links limit sliding. As a result, the forces exerted by the dynein arms cause the doublets to curve, bending the cilium or flagellum.
- **Microfilaments** are solid rods about 7 nm in diameter.
  - Each microfilament is built as a twisted double chain of actin subunits.
  - Microfilaments can form structural networks due to their ability to branch.
- The structural role of microfilaments in the cytoskeleton is to bear tension, resisting pulling forces within the cell.
- They form a three-dimensional network just inside the plasma membrane to help support the cell's shape, giving the cell cortex the semisolid consistency of a gel.
- Microfilaments are important in cell motility, especially as part of the contractile apparatus of muscle cells.
  - In muscle cells, thousands of actin filaments are arranged parallel to one another.
  - Thicker filaments composed of **myosin** interdigitate with the thinner actin fibers.

°Myosin molecules act as motor proteins, walking along the actin filaments to shorten the cell.

- In other cells, actin-myosin aggregates are less organized but still cause localized contraction.  
°A contracting belt of microfilaments divides the cytoplasm of animal cells during cell division.

°Localized contraction brought about by actin and myosin also drives amoeboid movement.

▪**Pseudopodia**, cellular extensions, extend and contract through the reversible assembly and contraction of actin subunits into microfilaments.

- \* Microfilaments assemble into networks that convert sol to gel.
- \* According to a widely accepted model, filaments near the cell's trailing edge interact with myosin, causing contraction.
- \* The contraction forces the interior fluid into the pseudopodium, where the actin network has been weakened.
- \* The pseudopodium extends until the actin reassembles into a network.
- In plant cells, actin-myosin interactions and sol-gel transformations drive **cytoplasmic streaming**.  
°This creates a circular flow of cytoplasm in the cell, speeding the distribution of materials within the cell.
- **Intermediate filaments** range in diameter from 8–12 nanometers, larger than microfilaments but smaller than microtubules.
- Intermediate filaments are a diverse class of cytoskeletal units, built from a family of proteins called keratins.  
°Intermediate filaments are specialized for bearing tension.
- Intermediate filaments are more permanent fixtures of the cytoskeleton than are the other two classes.
- They reinforce cell shape and fix organelle location.

## G. Cell Surfaces and Junctions

### Objectives:

1. Describe the basic structure of a plant cell wall.
2. Describe the structure and list four functions of the extracellular matrix in

- animal cells.
3. Explain how the extracellular matrix may act to integrate changes inside and outside the cell.
  4. Name the intercellular junctions found in plant and animal cells and list the function of each type of junction.

### **Misconception:**

1. It is important to emphasize that cells are not the static, rigid structures familiar to students from schematic drawings and electron micrographs. The term *cytoskeleton* is taken by some students to imply permanent scaffolding within the cell. Emphasize the continuous assembly and disassembly of cytoskeletal components and the role of the cytoskeleton in movements of organelles. Discuss the flow of membranes and other materials between organelles when teaching about the endomembrane system. Remind students that mitochondria and chloroplasts vary in shape between cells and move and change shape within cells. The message about the dynamic nature of a living cell is best taught by use of time-lapse movies.

#### ***1. Plant cells are encased by cell walls.***

- The **cell wall**, found in prokaryotes, fungi, and some protists, has multiple functions.
- In plants, the cell wall protects the cell, maintains its shape, and prevents excessive uptake of water.
- It also supports the plant against the force of gravity.
- The thickness and chemical composition of cell walls differs from species to species and among cell types within a plant.
- The basic design consists of microfibrils of cellulose embedded in a matrix of proteins and other polysaccharides. This is the basic design of steel-reinforced concrete or fiberglass.
- A mature cell wall consists of a **primary cell wall**, a **middle lamella** with sticky polysaccharides that holds cells together, and layers of **secondary cell wall**.
- Plant cell walls are perforated by channels between adjacent cells called plasmodesmata.

#### ***2. The extracellular matrix (ECM) of animal cells functions in support, adhesion, movement, and regulation.***

- Though lacking cell walls, animal cells do have an elaborate **extracellular matrix (ECM)**.
- The primary constituents of the extracellular matrix are glycoproteins, especially **collagen** fibers, embedded in a network of glycoprotein **proteoglycans**.
- In many cells, **fibronectins** in the ECM connect to **integrins**, intrinsic membrane proteins that span the membrane and bind on their cytoplasmic side to proteins attached to microfilaments of the cytoskeleton.
  - °The interconnections from the ECM to the cytoskeleton via the fibronectin-integrin link permit the integration of changes inside and outside the cell.
- The ECM can regulate cell behavior.
  - °Embryonic cells migrate along specific pathways by matching the orientation of their microfilaments to the “grain” of fibers in the extracellular matrix.
  - °The extracellular matrix can influence the activity of genes in the nucleus via a combination of chemical and mechanical signaling pathways.
    - This may coordinate the behavior of all the cells within a tissue.

#### ***3. Intercellular junctions help integrate cells into higher levels of structure and function.***

- <BL1>Neighboring cells in tissues, organs, or organ systems often adhere, interact, and communicate through direct physical contact.

- Plant cells are perforated with **plasmodesmata**, channels allowing cytosol to pass between cells.
  - Water and small solutes can pass freely from cell to cell.
  - In certain circumstances, proteins and RNA can be exchanged.
- Animals have 3 main types of intercellular links: tight junctions, desmosomes, and gap junctions.
- In **tight junctions**, membranes of adjacent cells are fused, forming continuous belts around cells.
  - This prevents leakage of extracellular fluid.
- **Desmosomes** (or anchoring junctions) fasten cells together into strong sheets, much like rivets.
  - Intermediate filaments of keratin reinforce desmosomes.
- **Gap junctions** (or communicating junctions) provide cytoplasmic channels between adjacent cells.
  - Special membrane proteins surround these pores.
  - Ions, sugars, amino acids, and other small molecules can pass.
  - In embryos, gap junctions facilitate chemical communication during development.

### 3. *A cell is a living unit greater than the sum of its parts.*

- While the cell has many structures with specific functions, all these structures must work together.
  - For example, macrophages use actin filaments to move and extend pseudopodia to capture their bacterial prey.
  - Food vacuoles are digested by lysosomes, a product of the endomembrane system of ER and Golgi.
- The enzymes of the lysosomes and proteins of the cytoskeleton are synthesized on the ribosomes.
- The information for the proteins comes from genetic messages sent by DNA in the nucleus.
- All of these processes require energy in the form of ATP, most of which is supplied by the mitochondria.
- A cell is a living unit greater than the sum of its parts.

## Key Terms

actin	chromatin	cytoskeleton
basal body	chromosome	cytosol
cell fractionation	cilium	desmosome
cell wall	collagen	dynein
central vacuole	contractile vacuole	electron microscope (EM)
centriole	crista	endomembrane system
centrosome	cytoplasm	endoplasmic reticulum (ER)
chloroplast	cytoplasmic streaming	eukaryotic cell



extracellular matrix (ECM)  
 fibronectin  
 flagellum  
 food vacuole  
 gap junction  
 glycoprotein  
 Golgi apparatus  
 granum  
 integrin  
 intermediate filament  
 light microscope (LM)  
 lysosome  
 microfilament  
 microtubule  
 middle lamella  
 mitochondrial matrix

mitochondrion  
 myosin  
 nuclear envelope  
 nuclear lamina  
 nucleoid  
 nucleolus  
 nucleus  
 organelle  
 peroxisome  
 phagocytosis  
 plasma membrane  
 plasmodesma  
 plastid  
 primary cell wall  
 prokaryotic cell  
 proteoglycan

pseudopodium  
 ribosome  
 rough ER  
 scanning electron  
 microscope (SEM)  
 secondary cell wall  
 smooth ER  
 stroma  
 thylakoid  
 tight junction  
 tonoplast  
 transmission electron  
 microscope (TEM)  
 transport vesicle  
 ultracentrifuge  
 vesicle

## Word Roots

**centro-** the center; **-soma** a body (*centrosome*: material present in the cytoplasm of all eukaryotic cells and important during cell division)

**chloro-** green (*chloroplast*: the site of photosynthesis in plants and eukaryotic algae)

**cili-** hair (*cilium*: a short, hairlike cellular appendage with a microtubule core)

**cyto-** cell (*cytosol*: a semifluid medium in a cell in which organelles are located)

**-ell** small (*organelle*: a small, formed body with a specialized function found in the cytoplasm of eukaryotic cells)

**endo-** inner (*endomembrane system*: the system of membranes within a cell that includes the nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and the plasma membrane)

**eu-** true (*eukaryotic cell*: a cell that has a true nucleus)

**extra-** outside (*extracellular matrix*: the substance in which animal tissue cells are embedded)

**flagell-** whip (*flagellum*: a long, whiplike cellular appendage that moves cells)

**glyco-** sweet (*glycoprotein*: a protein covalently bonded to a carbohydrate)

**lamin-** sheet/layer (*nuclear lamina*: a netlike array of protein filaments that maintains the shape of the nucleus)

**lyso-** loosen (*lysosome*: a membrane-bounded sac of hydrolytic enzymes that a cell uses to digest macromolecules)

**micro-** small; **-tubul** a little pipe (*microtubule*: a hollow rod of tubulin protein in the cytoplasm of almost all eukaryotic cells)

**nucle-** nucleus; **-oid** like (*nucleoid*: the region where the genetic material is concentrated in prokaryotic cells)

**phago-** to eat; **-kytos** vessel (*phagocytosis*: a form of cell eating in which a cell engulfs a smaller organism or food particle)

**plasm-** molded; **-desma** a band or bond (*plasmodesmata*: an open channel in a plant cell wall)

**pro-** before; **-karyo** nucleus (*prokaryotic cell*: a cell that has no nucleus)

**pseudo-** false; **-pod** foot (*pseudopodium*: a cellular extension of amoeboid cells used in moving and feeding)

**thylaco-** sac or pouch (*thylakoid*: a series of flattened sacs within chloroplasts)

**tono-** stretched; **-plast** molded (*tonoplast*: the membrane that encloses a large central vacuole in a mature plant cell)

**trans-** across; **-port** a harbor (*transport vesicle*: a membranous compartment used to enclose and transport materials from one part of a cell to another)

**ultra-** beyond (*ultracentrifuge*: a machine that spins test tubes at the fastest speeds to

separate liquids and particles of different densities)

**vacu-** Empty (*vacuole*: sac that buds from the ER, Golgi, or plasma membrane)